Technical Report 151

LITHIUM HYDROXIDE CANISTERS FOR PERSONNEL SHELTERS

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U. S. NAVAL CIVIL ENGINEERING LABORATORY

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Errata Sheet

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Technical Report R-151

"Lithium Hydroxide Canisters for Personnel Shelters"

On page 13, paragraph 1, line 6,

change 0.9 pound of CO_2 per hour to .09 pound.

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LITHIUM HYDROXIDE CANISTERS FOR PERSONNEL SHELTERS

AFWO 59-00-15

Type C Final Report

by

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OBJECT OF TASK

To develop a hand-operated blower for the standard lithium hydroxide canister for use in personnel shelters.

ABSTRACT

Because present hand-operated blowers at low crank speeds would not deliver enough air for a personnel shelter through the standard lithium hydroxide canister, a canister-blower device with two canisters paralleled was developed by NCEL. The device will deliver 15 cfm of air with 3-percent CO_2 at a crank speed of 29 rpm.

The unit reduced the CO_2 in a 500-cubic-foot sealed room from about 3 to 1/2 percent during the first hour's run; in subsequent runs the reduction from 3 percent became succeedingly less. During the eighth and final run the concentration was reduced to just 2 percent.

Good performance was obtained when air with 3-percent CO_2 was passed through a canister at 7-1/2 cfm. When CO_2 is removed at this rate, one canister per eight people will last six hours; this will maintain about a 3-percent CO_2 level in shelters. About 5000 Btu of heat and 2 pounds of water were released per canister for this period. The 3-percent CO_2 concentration is satisfactory for a day or two; however, NRL reports a limit of 1-percent CO_2 for longer periods.

Desiccant canisters are needed to remove water vapor. A ratio of two silica gel canisters to five lithium hydroxide canisters will remove water from the CO_2 reaction; a ratio of two to one will remove additional water generated by occupants.

Operational instructions are appended, with a chart showing when and how to use the equipment.

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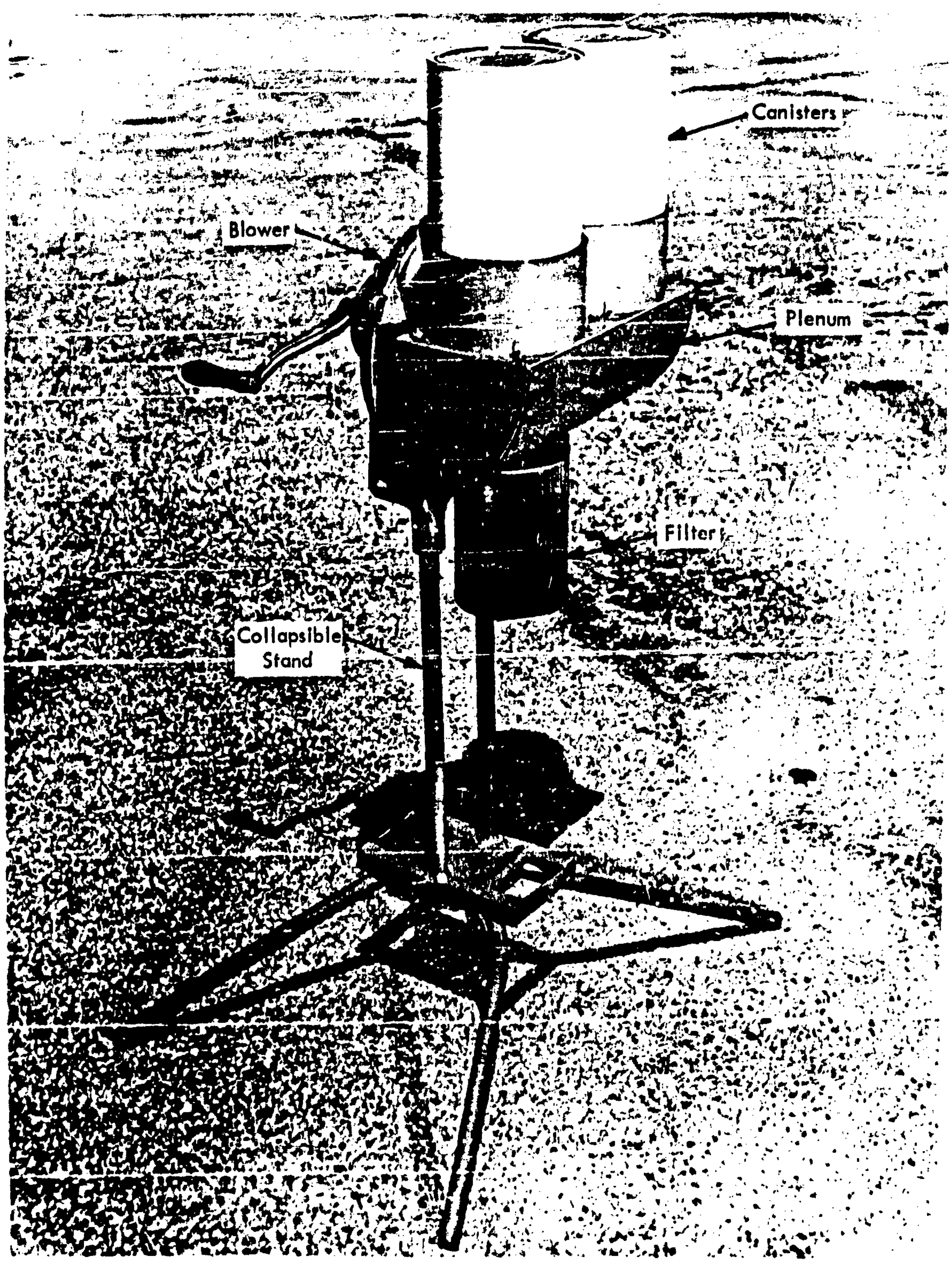

Figure 1. Lithium hydroxide canister-blower device with canisters in place.

INTRODUCTION

The Potomac River Naval Command has a personnel shelter program which needs a hand-operated blower for use with the Navy standard lithium hydroxide (LiOH) canister. The task of selecting or developing a suitable blower, fitting it to the canister, and testing the completed device in air of known CO_2 concentrations was assigned to the U. S. Naval Civil Engineering Laboratory. Desirable features were compactness, portability, and that it be reasonably easy for one man to operate. It was suggested that performance tests of the device be conducted with CO_2 concentrations in the range of 2 to 3 percent and that blower crank speeds should be about 20 rpm.

DESCRIPTION

Lithium Hydroxide Canister

The canister is a metal can approximately 6-1/2 inches in diameter and 11-3/4 inches high, with perforated ends for the passage of air. It holds approximately 6.4 pounds of anhydrous LiOH (4 to 14 sieve). A pressed-fit lid on each end, much like the lid on a paint can, keeps the LiOH sealed from the atmosphere while in storage. The canister specification is MIL-C-21004(SHIPS); the LiOH specification is MIL-L-20213C(SHIPS).

Blowers

It was decided that a hand-operated blower which would deliver 15 cfm through the canister would be satisfactory for shelter use. (The Naval Research Laboratory stated that air can be drawn through a canister at rates from 10 to 14 cfm at suction pressures of about 3 inches water gauge.*)

Although air delivery rates versus static pressures of commercial hand-operated blowers were not given in manufacturers' catalogs, three blowers appeared to be satisfactory and were purchased:

1. Champion Blower and Forge with a 6-inch-diameter wheel

2. Champion Blower and Forge with a 10-inch-diameter wheel

3. Buffalo Forge with a 10-inch-diameter wheel

* U. S. Naval Research Laboratory letter, 6130-165A:RRM:be, NRL Prob C08-05, of 13 January 1959.

These were tested with a canister attached and found unsatisfactory. The 6-inch Champion was unable to deliver the desired air flow of 15 cfm. The other two delivered the desired flow rates, but only at crank speeds above 50 rpm; much higher than the suggested 20 rpm. The 10-inch Champion was then modified by placing 1-inch extensions on the fan blades, thus making essentially a 12-inch wheel. The crank speed was further reduced, but it was still above 40 rpm.

NCEL then fabricated its own blower. It is similar to the unmodified 10-inch Champion, except the wheel is 12 inches in diameter and the clearance between the blade tips and the scroll housing is reduced. Again performance was improved, but yet a crank speed of 34 rpm was necessary to obtain 15 cfm.

Canister-Blower Device

The NCEL prototype lithium hydroxide canister-blower device was then developed, as shown in Figure 1. It consists of two paralleled canisters, a blower, a small plenum which holds the canisters, a jet aircraft type fuel filter, and a collapsible stand. The assembly is 4 feet high and weighs 46 pounds. When the blower is operated, room air is drawn into the canisters, passed through the plenum, discharged into the filter, and then returned to the room. Filtering keeps any lithium hydroxide dust from being discharged into the shelter; this dust irritates the respiratory system. A cork in the bottom of the filter is removed when no more dust is being generated, after about 5 minutes of operation, allowing the air to by-pass the filter.

The device with the NCEL blower delivered 15 cfm (7-1/2 cfm per canister) at a crank speed of 21 rpm when the filter was by-passed. The CO_2 reaction increased the speed to 29 rpm, but this performance was accepted as satisfactory. (The modified Champion delivered 15 cfm at 21 and 33 rpm, respectively.) With the filter, the crank speeds are increased from 10 to 20 percent, depending upon the blower used.

Test Chamber

Performance tests of the canister-blower device were made in a sealed test chamber. The chamber, which was nearly cubicle, with a volume of approximately 500 cubic feet, was sealed by spraying the interior surface with a Saran plastic. During tests the 2-foot by 6-foot door was held tightly closed by three bar-and-wedge type latches. CO_2 leak tests of the sealed chamber, with all instruments and equipment in place, gave a half-life of 20 hours.

METHOD OF TEST AND INSTRUMENTATION

Canister Air Flow

The canister-blower device was used to determine air flows through the canisters. A venturi tube attached to the blower outlet measured the air flow and a micromanometer on the plenum measured the static pressure. The blower was operated at several speeds and the resultant cfm and static pressures were tabulated. When one canister was being tested, the plenum hole for the other canister was sealed shut.

Blower Capacity

The capacity of each blower was determined by measuring the air volume and static pressure at fixed wheel speeds. The blower, with a duct 4 feet long and 4 inches in diameter attached, was operated by a variable-speed motor. The tests began at a crank speed of 15 rpm as determined by a tachometer. This meant a blower speed of 720 rpm since the gear ratio was 48 to 1. With the duct outlet closed, i.e. at zero air flow, the resultant static pressure in the duct was measured with the micromanometer. Then, keeping the wheel speed constant, the duct outlet was gradually opened, measuring static pressures and air flow rates in steps, until the blower was delivering about 60 cfm. An anemometer at the duct outlet measured the air flow rates. Blower capacities at crank speeds of 20, 25, 30, and 35 rpm were measured in the same way.

Sealed Chamber Tests (Diminishing CO_2 Concentration)

The sealed chamber tests were also made with the canister-blower device. The CO_2 concentration in the chamber was increased to 3 percent and the device, which was operated remotely, was adjusted to deliver about 20 cfm. Each test was for 60 minutes; CO_2 concentrations were read every 5 minutes from a Dwyer CO_2 analyzer, and wet- and dry-bulb temperatures were read from a motorized psychrometer. Blower tachometer and plenum micromanometer readings were also checked occasionally to be assured that air delivery rates remained constant. At the end of each hour the chamber was recharged to 3 percent and the test was repeated until the canister could no longer efficiently absorb CO_2. The hour or so needed to recharge the room to 3 percent precluded more than three tests per day.

Canister CO_2 Absorption (Steady 3-Percent Concentration)

Canister CO_2 absorption tests were made with single canisters. Figure 2 shows the test setup. Tests were made at 5, 7-1/2, and 10 cfm with a steady 3-percent CO_2 concentration. Two 30-cfm rotameters measured the air flow and CO_2 rates, and a Hayes Orsat, using a two-way cock, measured the inlet and outlet CO_2 concentrations. To determine the water generated by the canister, a thermocouple and a dew-point temperature

recorder measured the inlet air psychrometry and another thermocouple and dew-point recorder measured the outlet's psychrometry. Air for the test was supplied by an air compressor; the CO_2 by a standard 50-pound cylinder. The air and CO_2 were well mixed and their pressures were reduced to almost zero gauge before entering the canister.

Two preliminary 7-hour tests made at 10 cfm revealed the reaction pattern and the degree of saturation that could be expected. The tests indicated that after 4-1/2 hours of operation the rate of CO_2 absorption was poor. It was discovered that if the canisters were then allowed to rest for 30 minutes, they reacted sharply when put back into operation. It was therefore decided that each canister would be operated for 4-1/2 hours and then be given a 30-minute rest period, followed by a second phase of operation which would continue until the efficiency again dropped off. The results later revealed that all three runs required virtually the same time cycle. The canisters were weighed before and after testing and also during the rest period.

RESULTS OF TESTS

Canister Air Flow and Blower Capacity

The curves shown in Figures 3 through 6 illustrate the results of the blower capacity tests. Superimposed on the fan curves are the system curves for one and two canisters for pure air and for air containing 3-percent CO_2. The pure air curves have a parabolic shape characteristic of ductwork systems, but the 3-percent curves have a different shape, showing considerable increase in static pressure and rpm for the same cfm. When two canisters operate in parallel, the static pressure is somewhat higher than with a single canister under similar conditions, presumably because of additional air turbulence.

Sealed Chamber Tests (Diminishing CO_2 Concentration)

Figures 7 and 8 show the results of operating the canister-blower unit (with two canisters) in the sealed chamber. Figure 7 shows that the unit readily reduced the CO_2 concentration from about 3 to 1/2 percent during the first hour's operation. Ability to reduce the concentration diminished as the test progressed, until during the eighth hour the unit could reduce the concentration to only about 2 percent. Figure 8 shows the effect the canister operation had on chamber relative humidity and dry-bulb temperature. The relative humidity increased rapidly during the first half-hour and then decreased moderately during the remainder of the hour, while the dry-bulb temperature continued to rise throughout the run. The canister recuperated during chamber recharging, which accounts for the similar hourly test patterns. Little change occurred in the relative humidity during the eighth hour, indicating that the canister was nearly spent.

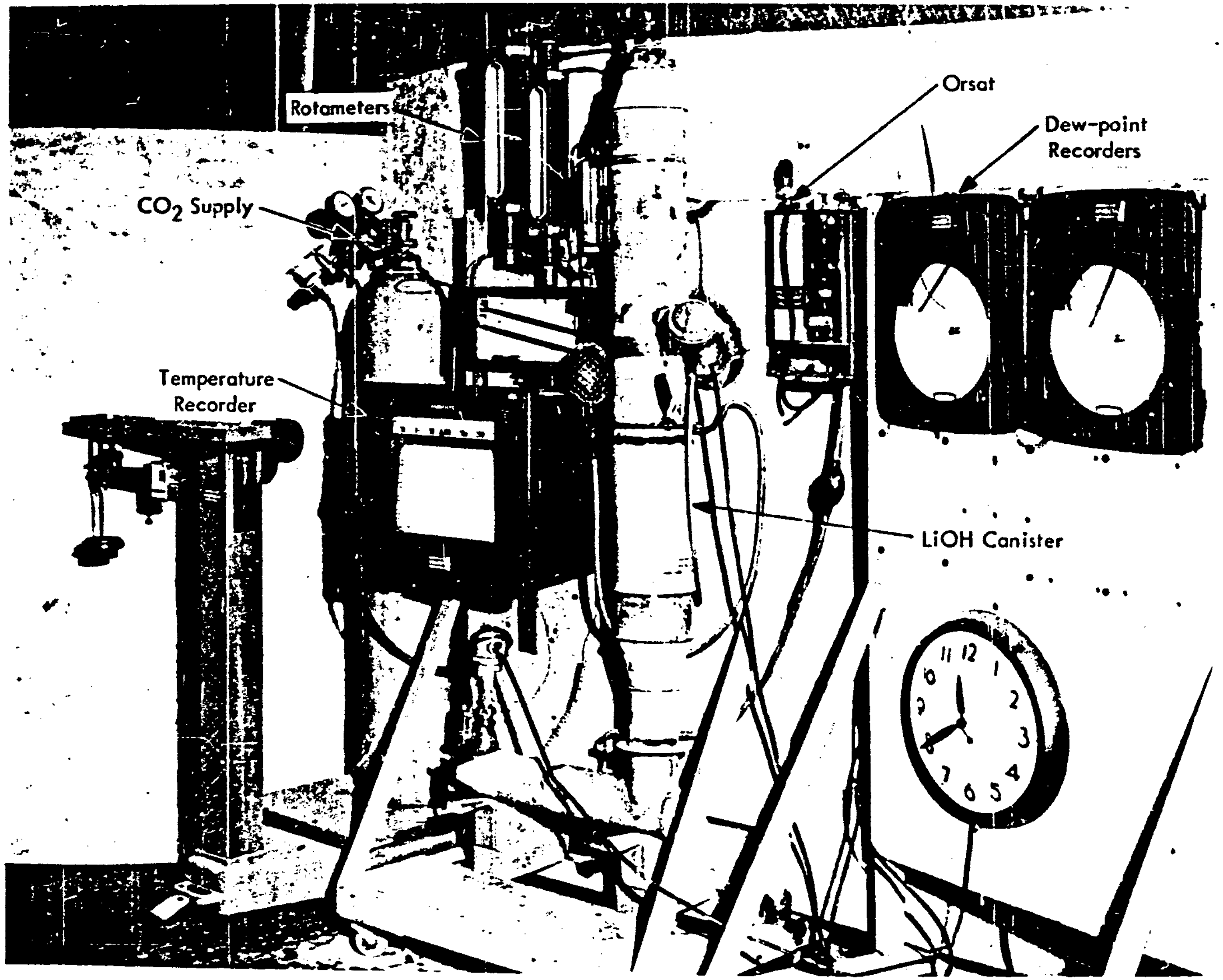

Figure 2. Test setup for canister absorption of CO_2 at a steady 3-percent level.

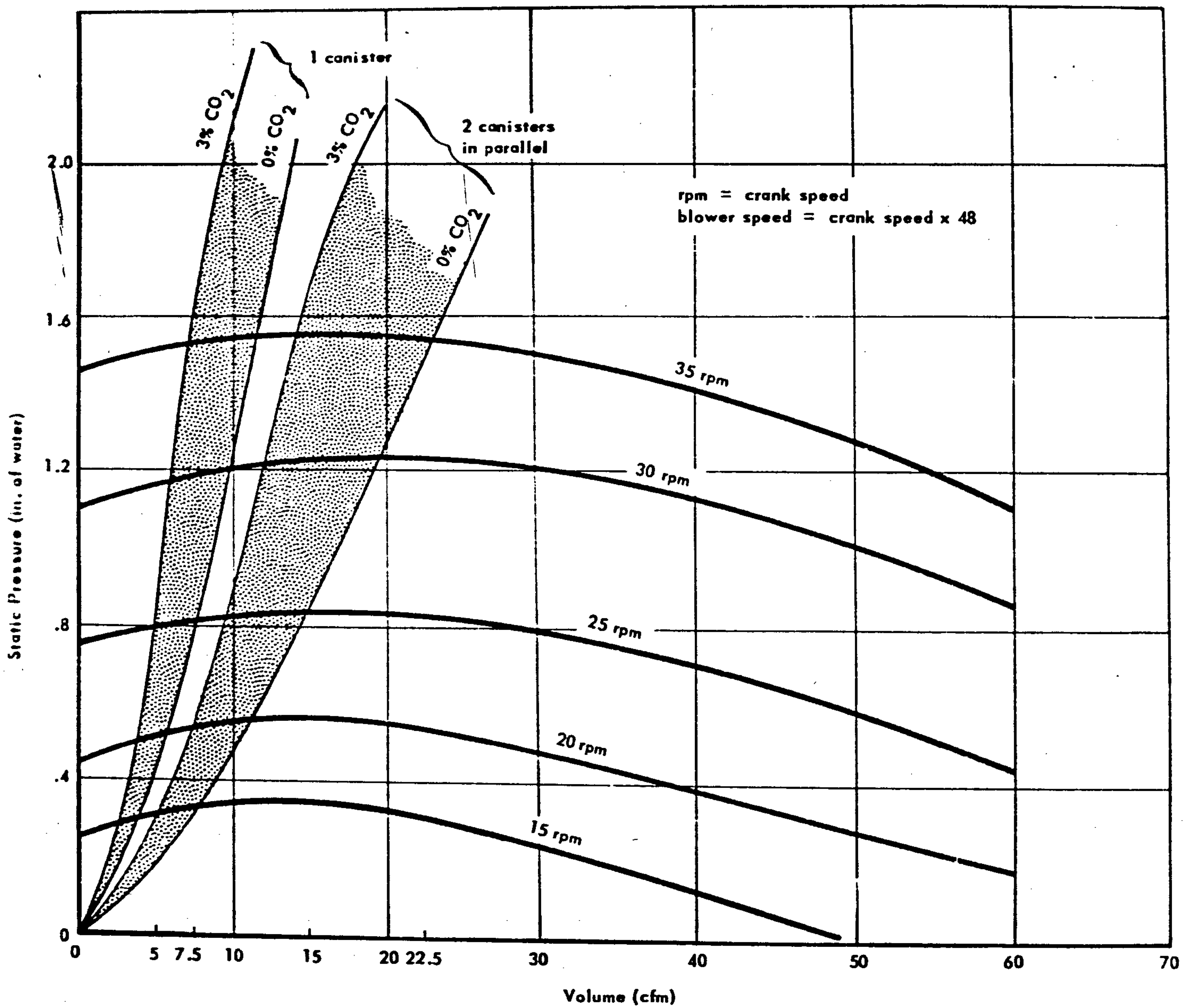

Figure 3. Flow characteristics of the 10-inch Champion blower.

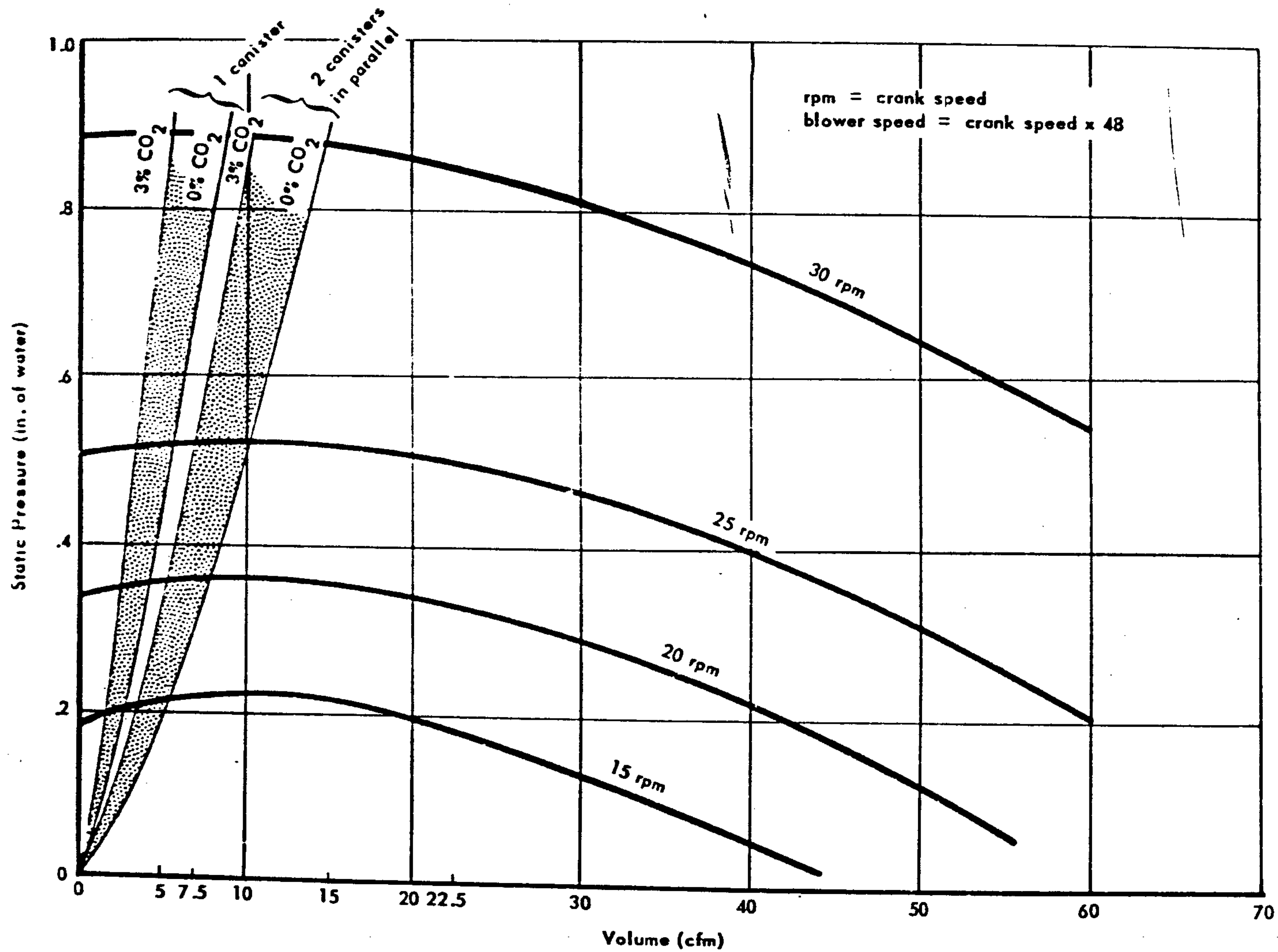

Figure 4. Flow characteristics of the 10-inch Buffalo-Forge blower.

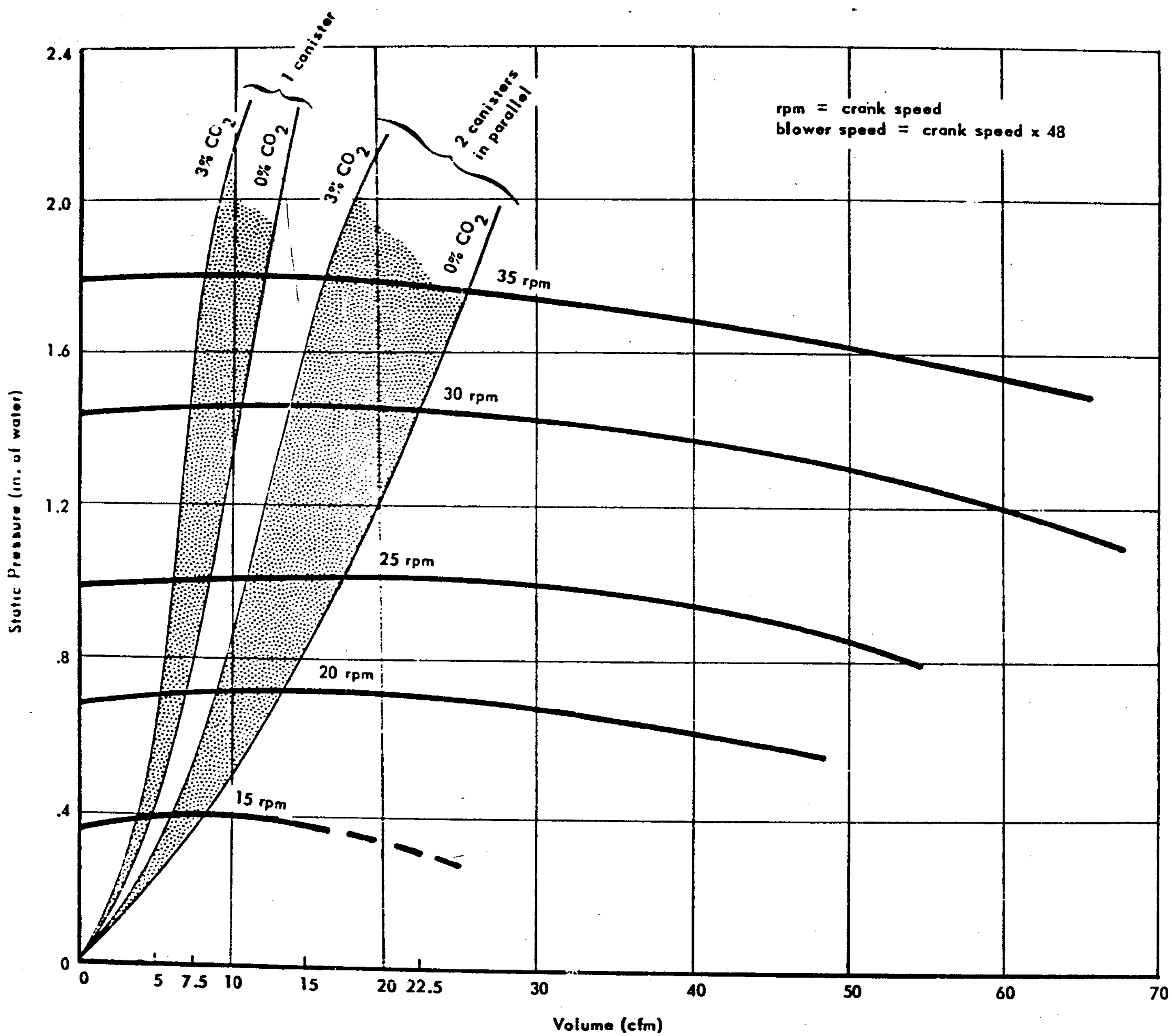

Figure 5. Flow characteristics of the 12-inch (modified) Champion blower.

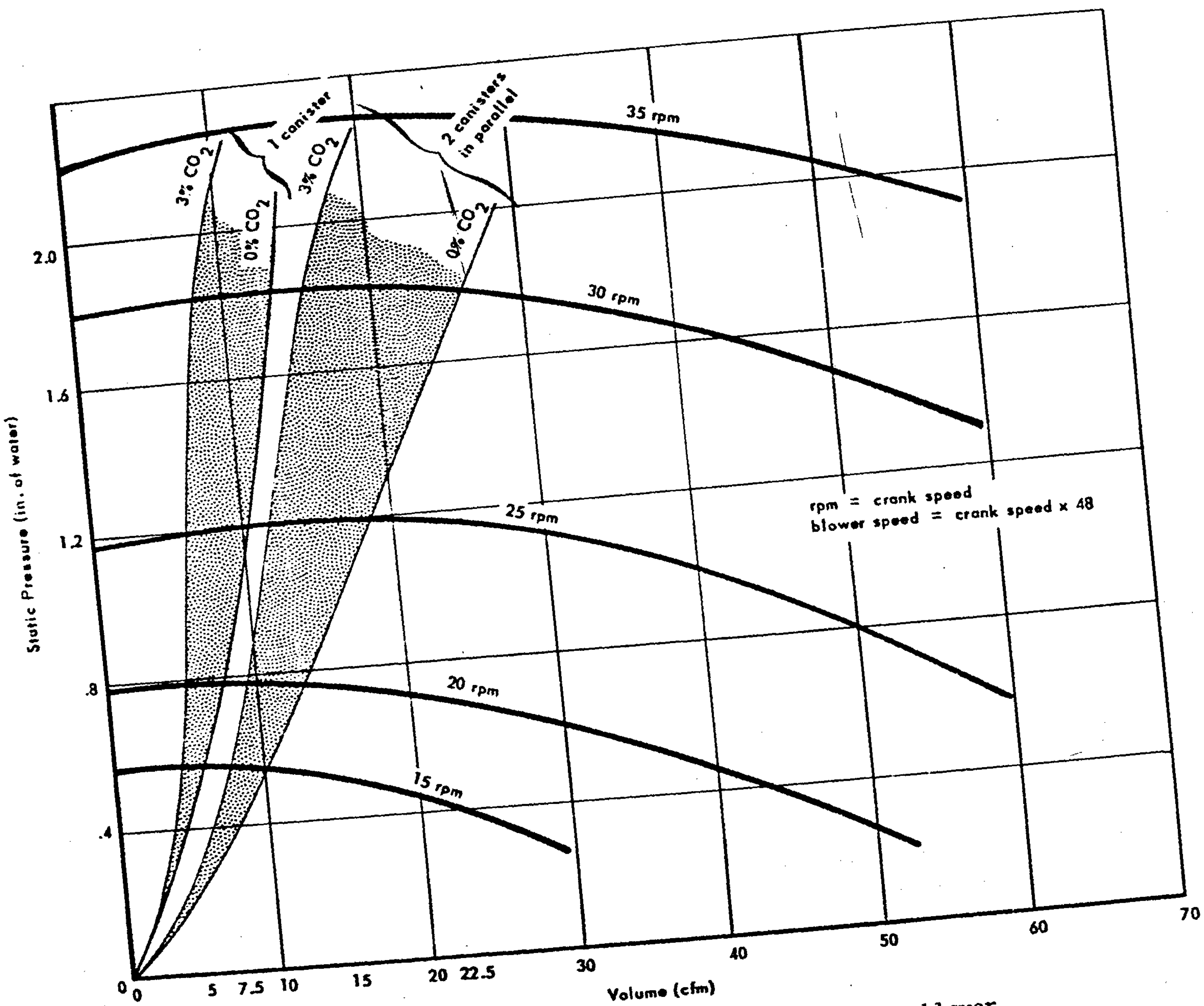

Figure 6. Flow characteristics of the 12-inch NCEL blower.

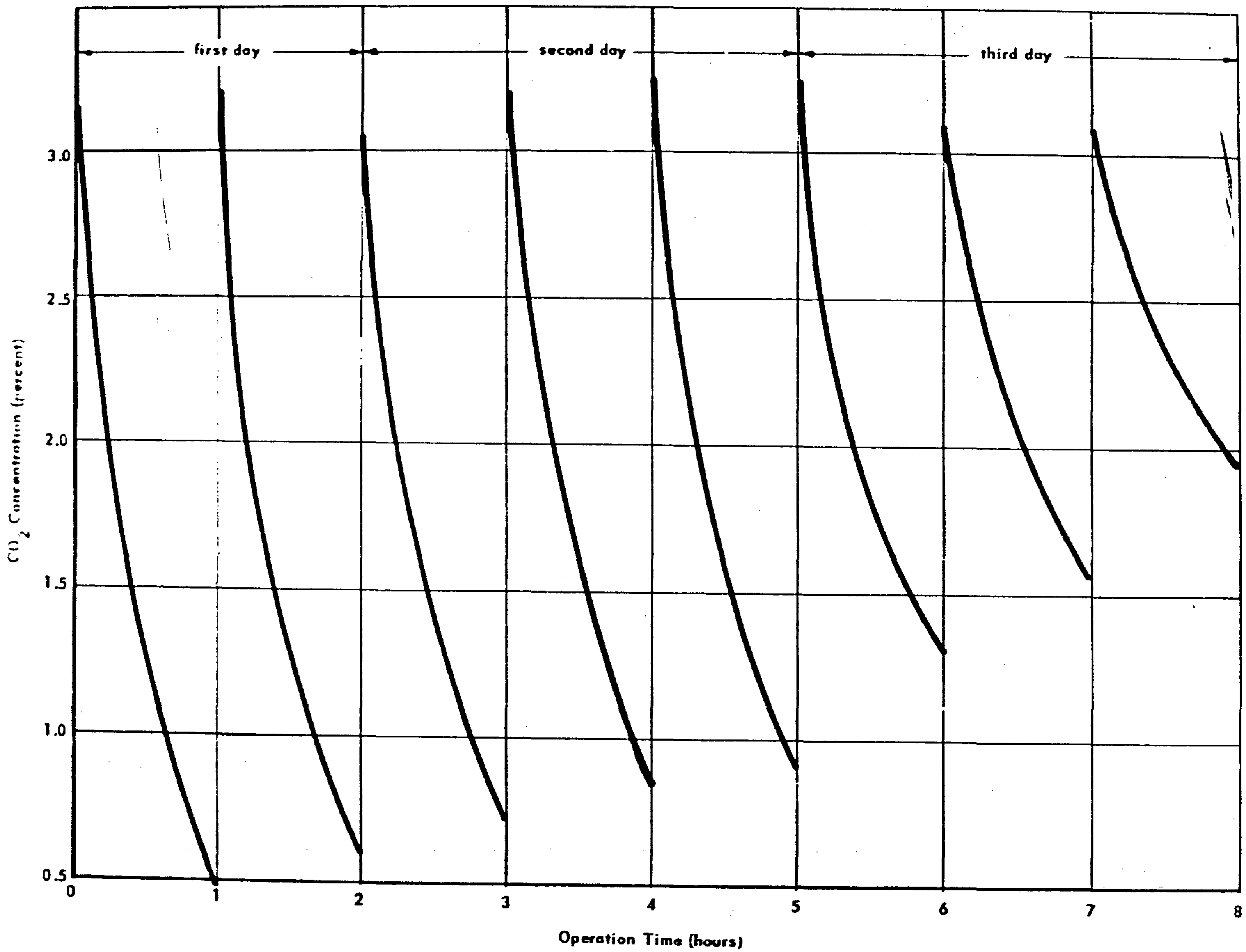

Figure 7. CO_2 concentrations in sealed chamber tests.

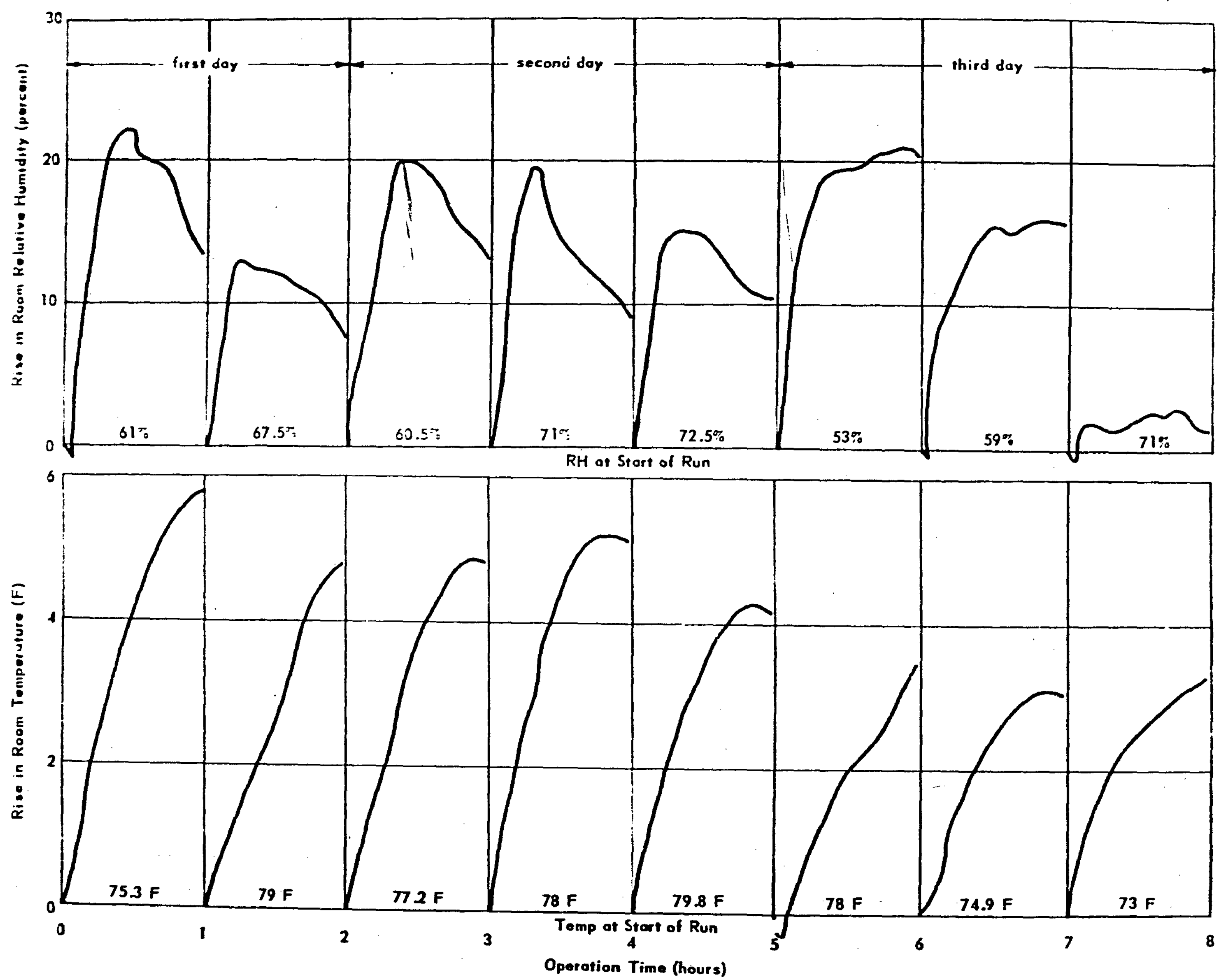

Figure 3. Psychrometric changes in sealed chamber tests.

Canister CO_2 Absorption (Steady 3-Percent Concentration)

Significant results of the steady 3-percent CO_2 flow tests are listed in Table I. The tabulations are either from direct measurements or were obtained by computation.

Table I. Results of Canister CO_2 Absorption Tests (Steady 3-Percent Concentration)

1.	Air flow rate, cfm	M*	10	7.5	5
2.	Length of test, hr	M	6.1	5.8	6.0
3.	LiOH originally in canister, lb	M	6.4	6.4	6.4
4.	CO_2 to canister, total for run, lb	M	13.10	10.46	6.00
5.	CO_2 absorbed by canister, lb	C	5.00	5.19	4.25
6.	CO_2 which theoretically can be absorbed, lb	C	5.86	5.86	5.86
7.	Degree of saturation (5 ÷ 6), percent	C	85.4	88.6	72.5
8.	Water generated (based on 5), lb	C	2.05	2.13	1.74
9.	Water generated (based on dew-point temp.), lb	C	1.69	1.78	1.74
10.	LiOH remaining in canister (based on 5), lb	C	0.94	0.73	1.76
11.	Li_2CO_3 formed in canister (based on 5), lb	C	8.41	8.74	7.14
12.	Weight of empty canister, lb	M	1.81	1.79	1.85
13.	Final weight (LiOH, Li_2CO_3, and canister), lb	M	11.56	11.31	10.69
14.	Weight unaccounted for [13 - (10 + 11 + 12)], lb	C	+0.40	+0.05	-0.06
15.	Maximum dry-bulb temperature of effluent, F	M	199.5	234.5	184.5
16.	Maximum dew-point temperature of effluent, F	M	83.0	98.3	89.5
17.	Maximum pressure difference across canister, in. H_2O	M	2.10	1.58	0.77
18.	Total heat released to effluent, Btu	C	5056	5022	4310

* M - measured
C - computed

Item 4 is the weight difference of the CO_2 cylinder before and after each run. Item 5, the CO_2 absorbed by the canister as computed from the Orsat analysis, shows that 7-1/2 cfm is the best rate. From this rate it can be determined that one canister is needed for every eight persons (operator figures as two), assuming the canister life to be 6 hours and that each person produces 0.9 pound of CO_2 per hour. Item 6, the weight of carbon dioxide which theoretically can be absorbed, is based on the formula $2\ LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O$. Items 8 and 9, water generated by the chemical reaction, show fairly good correlation although each was computed differently. Item 8 was determined by plugging item 5 into the chemical formula, and item 9 was determined psychrometrically by using the measured inlet and outlet dew-point temperatures. The heat released per canister, item 18, was calculated from the change in enthalpy of the inlet and outlet air. This heat, on an hourly basis, was approximately 720 Btu at 5 cfm and 840 Btu at 7-1/2 and 10 cfm.

The results also have been plotted as curves, Figures 9 through 12. The reaction pattern is best illustrated by Figure 9. During the first hour a strong reaction occurred followed by a steep decline, and then at the beginning of the third hour a second strong reaction occurred. From this point the reaction dropped off rather sharply until practically no CO_2 was being absorbed; after about 4-1/2 hours. Following the 30-minute rest period, another moderate reaction occurred which tailed off after 1-1/2 hours. This pattern was similar to the preliminary runs and occurred regardless of the air velocity or the mass flow of CO_2.

The dew-point curves, Figure 10, are rather erratic, but presumably the water was not released from the canister at the same rate at which it was formed.

DISCUSSION OF RESULTS

Crank speeds must be considered in relationship to crank length, gear ratio, and blower speed. Cranking the NCEL blower at a speed of 29 rpm was very convenient using the 48-to-1 gear ratio and a 10-inch crank. Cranking at the suggested 20 rpm is possible with a 70-to-1 gear ratio, but this would require a crank length of 14.3 inches. Crank lengths are based on a hand velocity of 2.5 feet per second as recommended by Marks.[1]

Lower flow rates through the canister result in more efficient absorption, but a minimum rate must be maintained to obtain the required mass flow of CO_2. Higher flow rates are limited by the static pressure, so a compromise must be reached between efficiency, pressure, and mass flow. The flow rate of 7-1/2 cfm seems to be best for the canister.

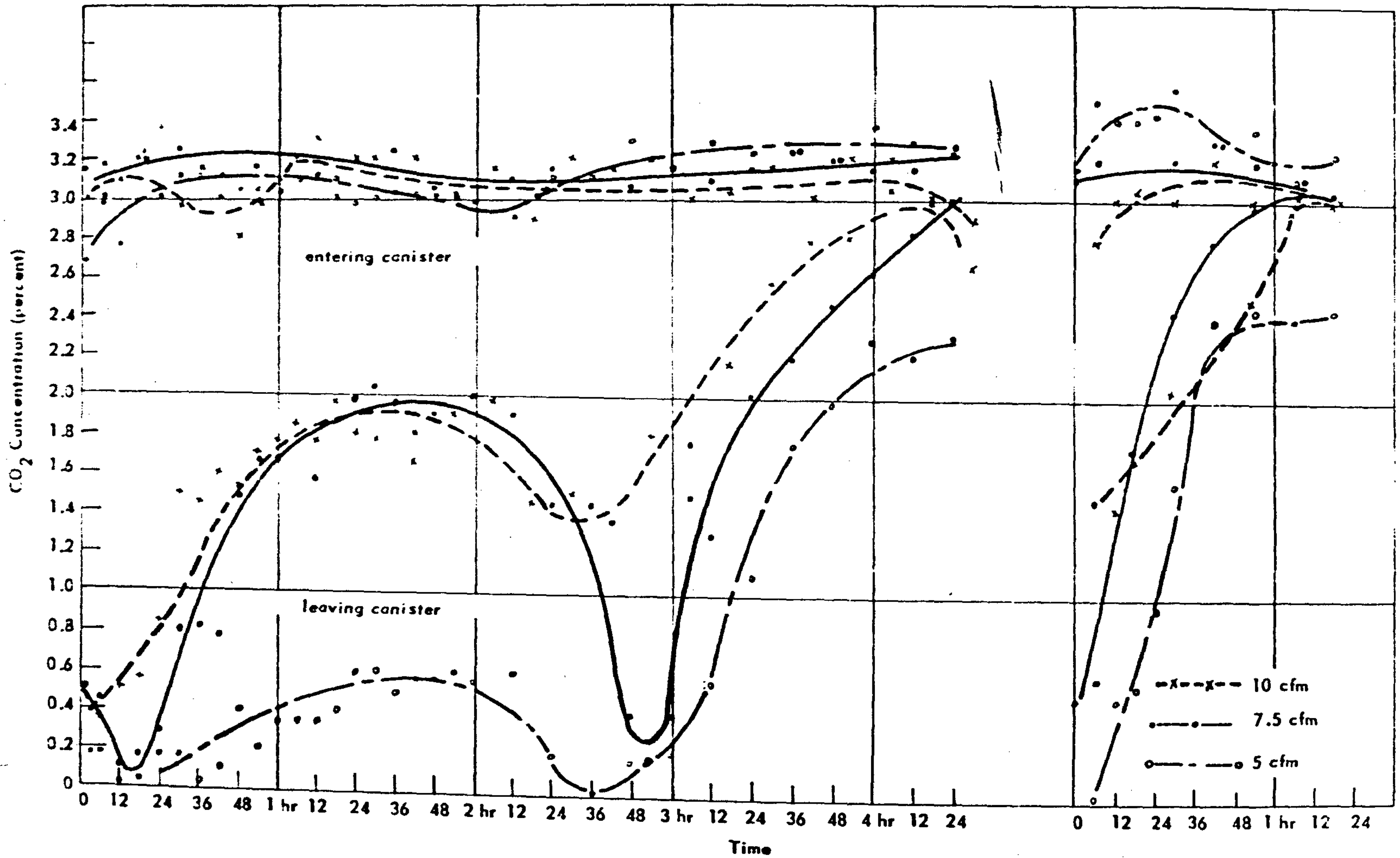

Figure 9. CO_2 concentrations entering and leaving the canister.

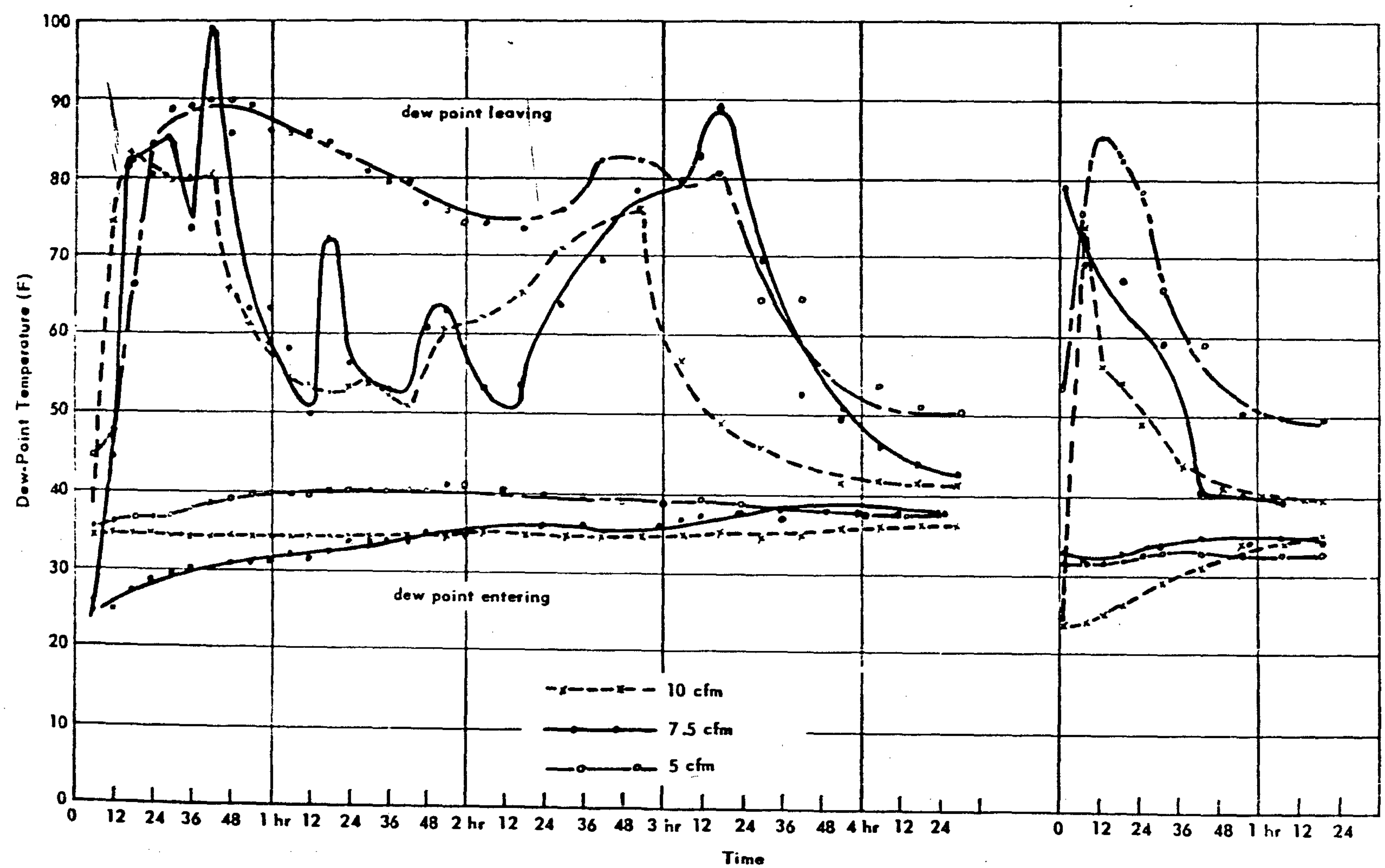

Figure 10. Dew-point temperatures of air-CO_2 mixture entering and leaving the canister.

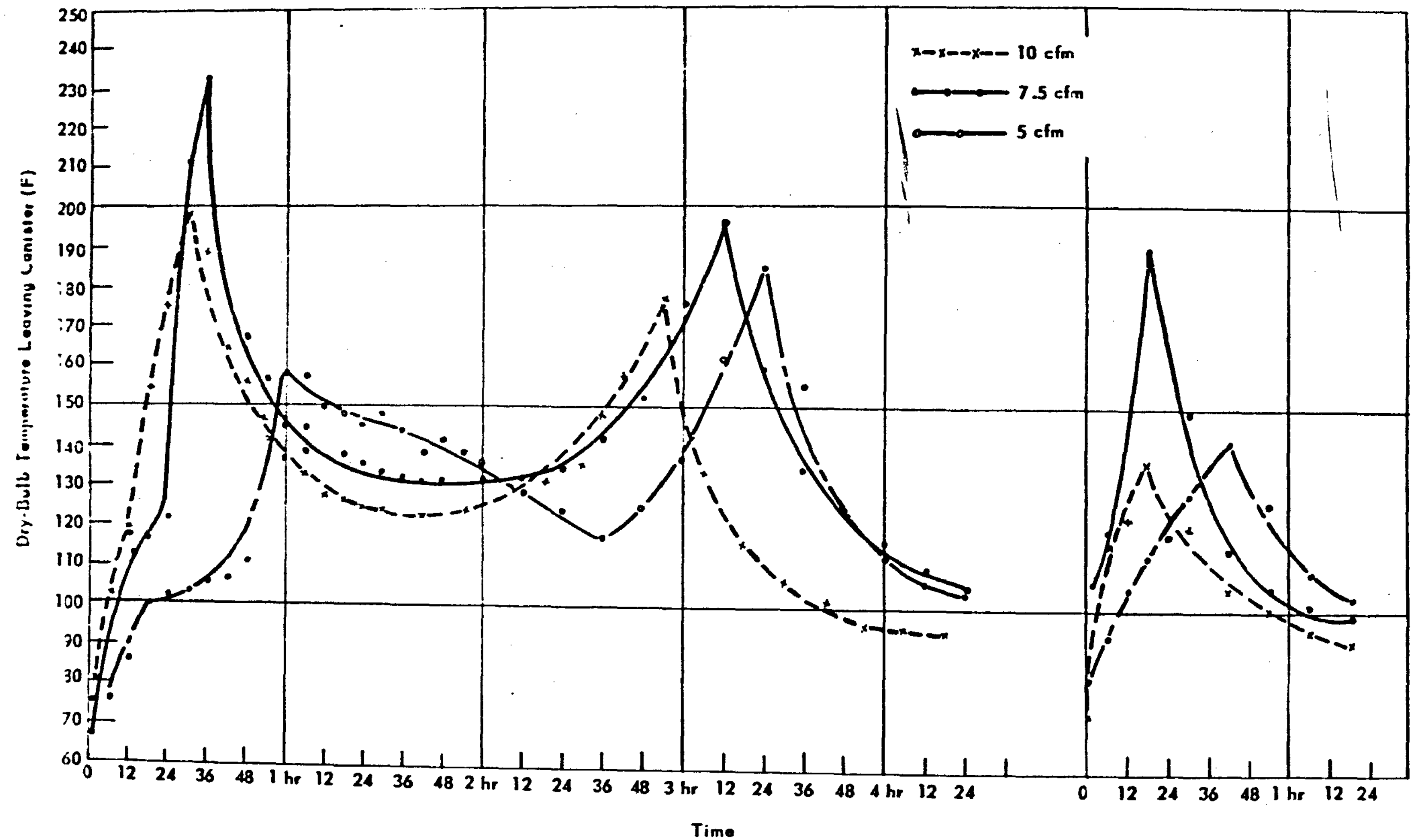

Figure 11. Dry-bulb temperatures of canister effluent.

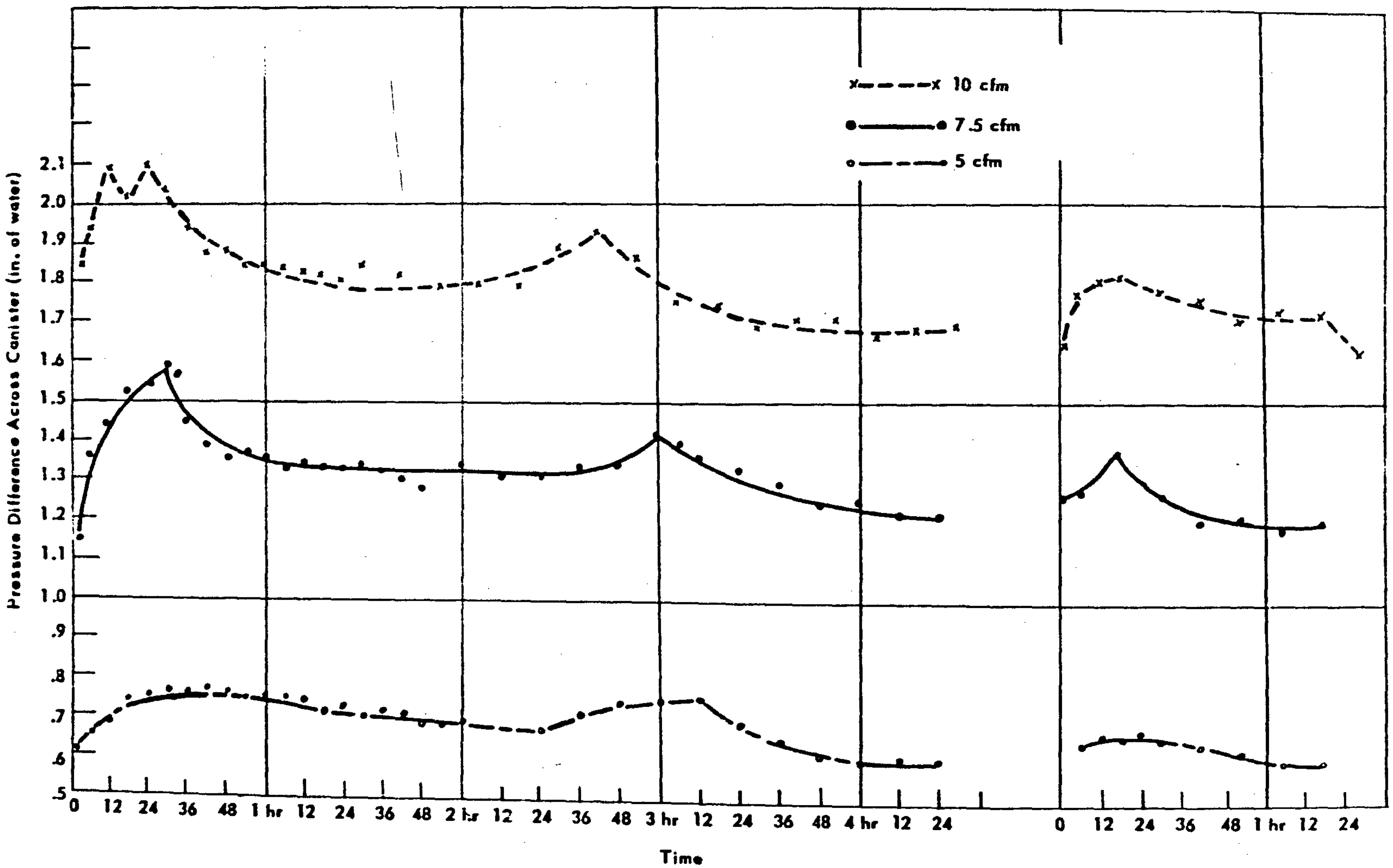

Figure 12. Pressure differentials of the canister.

If it is considered necessary to collect the water released by the LiOH, a desiccant must be used. Assuming the canister could also be used for silica gel (SiO_2), about 16 pounds of SiO_2 (4 to 14 sieve - same as LiOH) would fill it. Based on the ASHRAE guide,[2] 16 pounds of SiO_2 would adsorb about 5 pounds of water; the amount generated by 2-1/2 LiOH canisters. If the water generated by shelter occupants is also collected, ten SiO_2 canisters would be needed for every five LiOH canisters. For example, a fully occupied 50-man shelter would require 25 LiOH canisters and 50 SiO_2 canisters for 24 hours. The cost of these canisters would be $1500, assuming $28 for a LiOH canister and $15 for a SiO_2 canister. The number of blower units needed for the 50-person operation would be nine, which, at an estimated cost of $100 each in quantity production, would cost $900. Thus, the total cost to control CO_2 and water for 24 hours for 50 people would be $2400. Costs for other time periods are listed in Table II.

Table II. Approximate Cost to Remove CO_2 and Water for 50 Persons

Time Period	LiOH Canisters Needed	LiOH Canister Cost	SiO_2 Canisters Needed	SiO_2 Canister Cost	Blower Units Needed	Blower Unit Cost	Total Cost
6 hr	6	$ 150	12	$ 180	9	$900	$1230
12 hr	12	300	24	360	9	900	1560
24 hr	25	750	50	750	9	900	2400
48 hr	49	1370	98	1470	9	900	3740

The above table shows that cost of canisters becomes an important factor. The heat released is important also, particularly in warm climates. Fifty persons at rest produce approximately 20,000 Btu's per hour of total heat, and the canisters increase this to 25,040 Btu's per hour. The table is based on a 3-percent CO_2 level, which is the acceptable limit for a day or two according to the Chemical Warfare Laboratories.[3] For longer periods, the maximum limit is 1 percent, which is the upper level maintained in nuclear-powered submarines.[4]

The ordering, stocking, and inventorying of many canisters may be burdensome. The SiO_2 canisters perhaps could be eliminated by a single desiccant machine. A dehumidification machine has been developed which utilizes a corrugated asbestos-fiber wheel impregnated with a hygroscopic salt. This machine could be modified for hand-crank operation and easy renewal of the asbestos-fiber wheel. Cranking energy would not be excessive, perhaps 1/8 horsepower for a fully occupied 50-man shelter.

CANISTER OPERATING PROCEDURE

A proposed method of LiOH canister usage is given in the Appendix.

Although each canister requires at least a 30-minute rest after 4-1/2 hours of operation, there would be no discontinuity in the CO_2 removal because canisters from the stockpile could be substituted for those being rested. After 6 hours of operation, a canister is still capable of absorbing about 3/4 pound of CO_2, so that in a dire emergency the canisters could be used until they are completely spent. Evidence of reaction can be detected with the bare hand by feeling the can or effluent, since the heat evolved is proportional to the rate of absorption.

FINDINGS

1. A commercial hand-operated blower which would work satisfactorily with the standard lithium hydroxide canister could not be found. One built by NCEL worked better, but it too was unable to meet requirements.

2. The prototype canister-blower device using two canisters in parallel and the NCEL blower gave acceptable performance by delivering 15 cfm at a crank speed of 21 rpm with air, and 29 rpm with the CO_2 canister reaction. The device with the modified Champion blower would deliver 15 cfm at 21 rpm and 33 rpm, respectively.

3. The canister increases its static pressure as much as 100 percent when absorbing CO_2.

4. The canister does not remove CO_2 at a steady rate. Its most useful period is during the first 4-1/2 hours, but if allowed to rest for at least 30 minutes it will adsorb for another 1-1/2 hours.

5. Of the tests made, the canister absorbed best at 7-1/2 cfm.

6. If water from the CO_2 reaction is collected, a ratio of two silica gel canisters to five lithium hydroxide canisters is required. If water from the CO_2 reaction and occupants is collected, a ratio of two silica gel canisters to one lithium hydroxide canister is required.

CONCLUSIONS

1. The NCEL blower performed better than the others tested by delivering 15 cfm at 29 rpm during the CO_2 reaction. The suggested rate of 20 rpm could be obtained by using a speed reducer with a higher gear ratio (70 to 1), but with less favorable size and weight.

2. It would not be advisable to attach desiccant canisters in series to lithium hydroxide canisters because of the increase in static pressure. High static pressures are difficult to overcome with hand-operated equipment. If it is necessary to remove moisture, separate units containing paralleled desiccant canisters could be used; crank speed would be 21 rpm.

3. Because of the decreasing reaction pattern, a lithium hydroxide canister should not be used longer than 6 hours, with a 30-minute rest period at the end of 4-1/2 hours.

4. The canisters will absorb CO_2 satisfactorily if the method outlined in the Appendix is followed.

RECOMMENDATIONS

1. That a set of design drawings and specifications be prepared and a blower unit be built by a commercial manufacturer.

2. That the above blower unit be tested at NCEL preparatory to quantity production.

3. If desiccant canisters are to be required, that they be the same size as the lithium hydroxide canisters.

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3. Chemical Warfare Laboratories. Report No. 2177, Physiological Evaluation of a Diffusion Board Protective Shelter, by A. A. Woodward, et al. Army Chemical Center, Maryland, 3 April 1957. Page v.

4. Naval Research Laboratory. Report No. 5465, The Present Status of Chemical Research in Atmospheric Purification and Control on Nuclear-Powered Submarine, by R. R. Miller, et al. Washington, D. C., 21 April 1960. Page 19.

Appendix

PROCEDURE FOR LiOH CANISTER USAGE

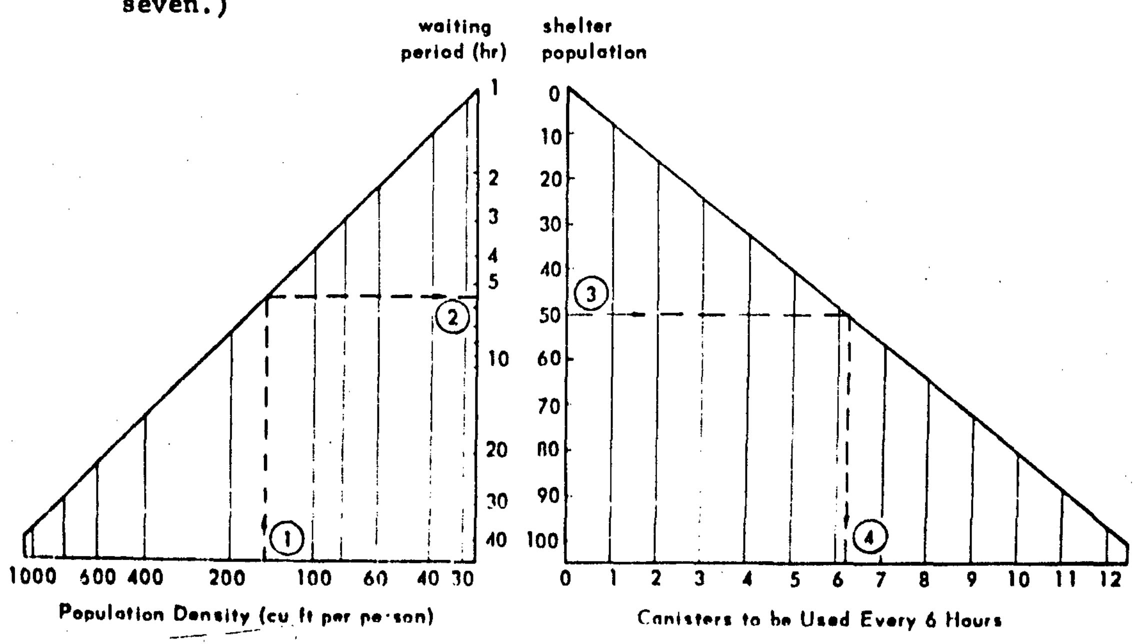
The canisters are not to be used until the CO_2 concentration in the shelter reaches 3 percent. Then the correct number of canisters are to be placed in operation to remove further additions of CO_2 at approximately the same rate at which it is generated by the occupants.

The chart below shows when and how to use the canisters. On the chart's left side, the "population density" (cubic feet per person) is connected vertically up to the sloping line and then horizontally right to the "waiting period." This gives the time period from initial occupancy until the 3-percent level is reached in the shelter. Moving to the chart's right side, the "shelter population" is connected horizontally right to the sloping line and then vertically down to the base, which gives the number of canisters to be used every 6 hours.

Example:

a. To find waiting period to 3-percent CO_2 level with a population density of 150, start at (1) and follow broken line to (2) . (5-1/2 hours.)

b. To find rate of canister usage with 50 persons in shelter, start at (3) and follow broken line to (4) . (Six-plus canisters. Use seven.)



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